THE EXTENT OF DAMAGE AND REPRODUCTION OF *TRIBOLIUM CONFUSUM* AND *T. CASTANEUM* IN WHEAT WITH DIFFERENT MOISTURE CONTENTS

by

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INTRODUCTION

The confused flour beetle, Tribolium confusum Duval, and the red flour beetle, T. castaneum Herbst, are well known insect pests of wheat flour and other cereal products in storage. Carried into flour mills with supplies of grain used in milling, they are not killed by grain cleaning operations or by the milling process so they become established throughout the milling units of a flour mill. According to Cotton (1943), they have been found to constitute more than 80 percent of the insect population of flour mills in the Southwest Milling Area. These insects infest a great variety of foods in addition to cereal products, and are known to cause serious damage in grocery stores and warehouses.

The flour beetles are cosmopolitan and have been recorded in practically every civilized country of the world. However, in the United States, T. confusum is more abundant in the northern part while T. castaneum is found mostly in the southern part of the country, although it has been recorded as far north as Canada. These beetles lay their eggs freely in flour and the larvae hatching from them feed and complete their growth as free living individuals. The developmental stages of Tribolium are comparatively short, but the adult life is among the longest recorded for the stored-product insects. In some cases, the adult life may be over three years.

Much work has been done with these insects in relation to flour but very little research has been done with the flour beetles in relation to whole grain. In the past it was thought that their mandibles were too weak to chew through the outer coating of grain. However, it has recently been demonstrated that the flour beetles can live and reproduce on whole kernel wheat.

The experimental work designed for this thesis has a two-fold purpose: first, to obtain information regarding the extent of damage to the wheat kernels by Tribolium confusum and T. castaneum; and second, to determine the extent of the ability of these insects to develop and reproduce on whole kernel uncracked wheat. For this reason a six months' study was made of these insects infesting wheat of three different moisture contents of approximately 10 percent, 12 percent and 14 percent and a temperature of 80° F.

REVIEW OF LITERATURE

The literature on the destruction of whole grain by beetles of the genus Tribolium is limited. Until recently it had been assumed that they lived either on the cracked kernels or on the "grain dust" caused by the abrasion of grains in handling or in the flour-like material resulting from the feeding of other insects. Upon observing these conditions, Birch (1947) became skeptical and conducted an experiment to test the point. Vials containing ten grams of wheat were set up with one pair, five pairs, and twenty pairs of adult Tribolium confusum and T. castaneum. The wheat was of medium hardness and only whole grains were used. Counts of larvae, pupae and adults were made at six week intervals for six months. It was evident that both species were able to live and reproduce in whole grain wheat. After six months, about one-third of the whole grains had been destroyed. Parkin (1944) stated that in different tests "broken grain" was employed because T. confusum was unable to feed on whole grain. According to Cotton (1943) insect pests of stored grain cannot breed in grain that has a moisture content of nine percent or lower. Most of these insects soon die in such grain. However, adult "bran bugs" are able to survive for long periods of time in dry wheat but little damage will be done since they are unable to multiply and do not feed on whole grain. Good (1936) also advanced the idea that the genus Tribolium cannot feed on whole grain because their mandibles are not strong enough to chew through the tough outer coating. Dean (1913) stated that while Tribolium confusum is primarily a flour pest, it also infests corn meal, cracked wheat, dry starchy material, stored peanuts, beans and even baking powder, ginger and cayenne pepper.

Good (1936) and Gray (1948) pointed out some distinguishing differences between the confused and the red flour beetle:

Flight. The confused flour beetle seldom, if ever, flies while the red species does so readily.

Eyes. The eyes of T. confusum are small and the space between them is about three times the diameter of the eye. Those of T. castaneum are large and separated by a space about equal to the eye diameter.

Antennae. The segments of the antennae of the confused flour beetle increase in size gradually from the base to the tip, whereas in the red flour beetle the last few segments of the antennae are abruptly much larger than the preceding ones, giving the antennae the appearance of being suddenly enlarged at the tip.

In rearing insects of the genus Tribolium Park (1934) stated that he preferred a non-bleached, white patent flour but most of the Tribolium workers seem to have favored whole wheat flour. Sun (1947) found common wheat flour to be the best culture medium. Cornstarch, whole wheat flour, enriched flour and tankage were also tried but patent flour was found to be best. Gray (1948) stated that whole wheat flour, whole wheat middlings, whole wheat meal and long extraction flours were all good media. He found, however, it was much better if the media were coarsely milled. The average time of larval development was greater on the finely ground material than the coarser particles. In a comparison of the rates of development of the beetles in various foods under uniform conditions, Chapman (1918) has shown that the life cycle may be longer on some foods than on others. This difference in development was confined largely to the last larval instar. Mickle and Standish (1946) found Tribolium confusum to be a much less serious pest of soy flours and grits than of cereal products.

Holdaway (1932) observed that larval development of the flour beetles was more rapid in higher humidities, the mean time being 22.6 days at 75 percent relative humidity, 25.5 days at

50 percent relative humidity and 30.1 days at 25 percent relative humidity. According to Good (1936) the average larval period, at 30 degrees Centigrade and 50 percent relative humidity, was about thirty days, the egg stage five days and the pupal stage about seven days. Chapman (1918) found there were at least six larval instars but also there may be as many as 12 due to external conditions and different types of food. Good (1936) stated that the flour beetles have a very long oviposition period. The life of the adult is more than one year. The oviposition period for the average female is about 280 days. According to Leslie and Park (1949), the most fertile period for a female Tribolium castaneum is from 6 to 60 days after emergence. After the adult has reached the age of 60 days, her ability to produce eggs begins to decrease.

MATERIALS AND EQUIPMENT

Experimental Insects

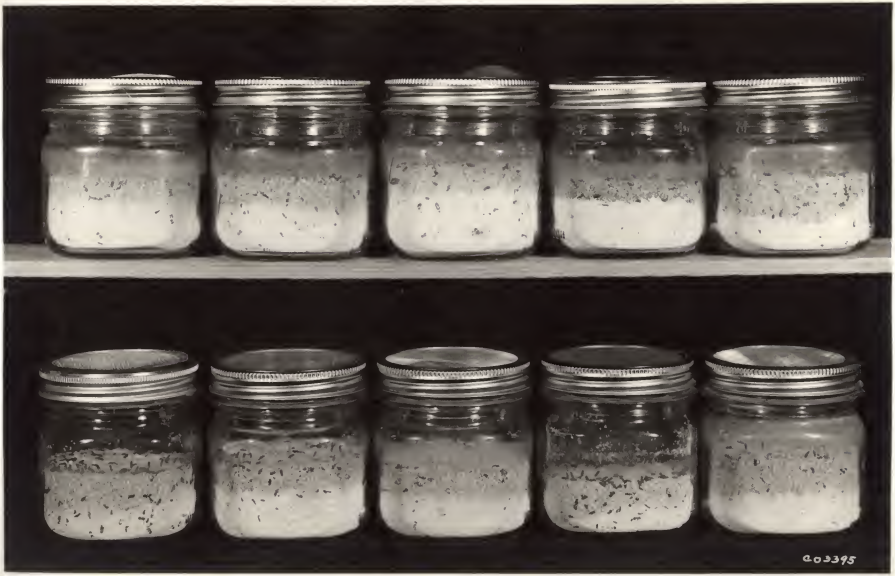
Source. The original stock from which the flour beetles were reared came from the Bureau of Entomology and Plant Quarantine at Manhattan, Kansas.

Maintenance of Stock Cultures. Stock cultures of adults of Tribolium confusum and T. castaneum were reared in wide-mouthed pint jars with 40 mesh screen lids, Plate I. Each jar contained about 100 grams of culture medium. This material consisted of approximately 40 percent white patent flour and 60 percent wheat middlings or shorts. About 250 adult beetles were placed in one

EXPLANATION OF PLATE I

Stock cultures of *Tribolium confusum* and *T. castaneum*

PLATE I



jar. The insects were allowed to remain in the jar for a period of seven days. This was sufficient time for them to deposit a large number of eggs. At the end of seven days they were separated from the medium by means of a 20 mesh screen sieve. The adults were then placed in a new jar containing the same amount of flour and shorts. The medium containing the eggs was put back into the original jar and the culture left undisturbed until the adults began to emerge. The reason for leaving the adults in the rearing jar for seven days was to get the maximum amount of reproduction and yet not give the adults time to consume a large number of their eggs. The confused flour beetle reproduced in much greater numbers than the red flour beetle in the culture medium provided. The addition of about one gram of powdered yeast to each jar of medium greatly increased the reproduction of T. castaneum.

These cultures were maintained in a rearing room under controlled conditions. The temperature was held constant at 80° F. (± 3° F.) and the relative humidity at 75 percent (± 5 percent). The average time from egg to the emergence of the adult under these conditions was from 38 to 43 days for T. confusum and from 34 to 42 days for T. castaneum.

Age and Sex of Beetles. In previous research by Leslie and Park (1949), it was found that the most fertile period for an adult female Tribolium castaneum was between the ages of 6 and 60 days. After the female has reached the age of 60 days her egg laying ability begins to decrease. For this reason insects between the ages of 6 and 15 days were used in this experiment. No attempt was made to separate the sexes of the beetles. According to Good (1936), of 800 T. confusum reared on whole wheat flour at 30° C., 52 percent were females and 48 percent were males. Under conditions similar to these there would be approximately 50 percent females which would insure sufficient reproduction for this investigation.

Wheat Used in Experiment

Source. The wheat used in this experiment was a mixture of the three varieties Pawnee, Red Chief and Triumph. This grain came from a collection of wheat taken from farm bins in Harvey County, Kansas.

Moisture Content. The original moisture content of the wheat ranged from 11.4 percent to 13.1 percent. To give a variation it was decided to use wheat with approximately 10 percent, 12 percent and 14 percent moisture content. Adjustments were made by placing small quantities of grain in the suitable humidifier and bringing it to the desired moisture content.

Humidity Control Apparatus

The sulfuric acid method of maintaining a constant humidity in small, closed containers was used in this work for the control of the humidity. This principle was employed by Curtis (1915) in his studies of hard rubber and other solid dielectrics. No claim of originality was made by Curtis. Stevens (1916) used the same method in rearing fungi on fruits at a certain humidity. This method consists in keeping the cultures in an atmosphere which is maintained at a constant humidity by exposure to an aqueous solution of sulfuric acid of known specific gravity. Other substances might be used to maintain a constant humidity but sulfuric acid is convenient to use and so slightly volatile that is apparently did not affect the insects.

It was found most convenient to use 8" x 10" x 15" battery jars as humidifiers, Plate II. The correct mixture of solution was put in the jar by pouring in the correct amount of water and then slowly adding to it the correct amount of concentrated sulfuric acid. Much care was shown in adding the acid to prevent the cracking of the battery jar. Two quart fruit jars were then placed on their sides in the bottom of the jar to act as piers. On these two jars rested a glass shelf 7 1/2" x 9" on which the small culture jars and the moisture check jar were placed. The lid of the humidifier was a piece of window glass 9" x 11". The top edge of the battery jar was greased with vaseline to prevent the entrance or escape of air which would have changed the relative humidity within the jar. The correct proportions at which to mix the sulfuric acid and water to obtain a certain relative humidity are shown in Table 1.

EXPLANATION OF PLATE II

Humidity control apparatus containing 12 sample jars and moisture check jar

PLATE II

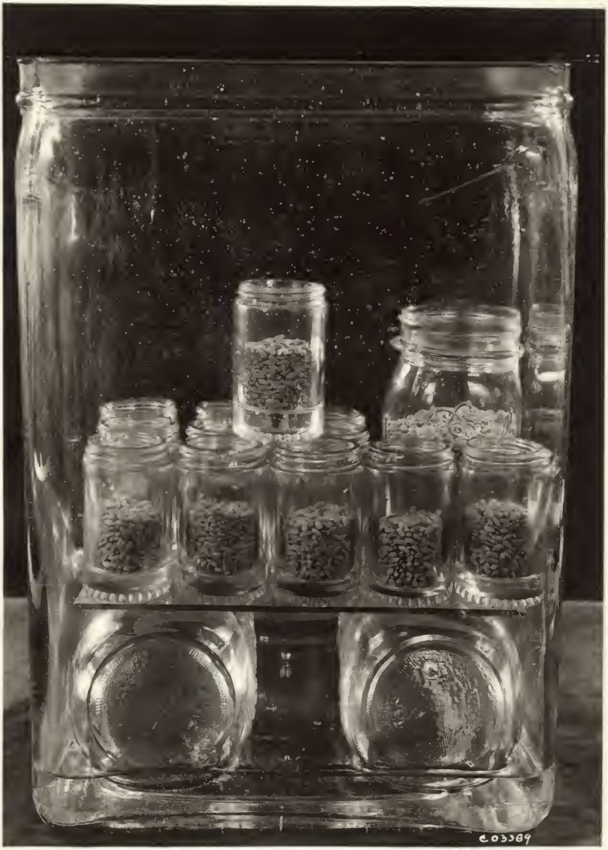


Table 1. Approximate relative humidities for dilute sulfuric acid at various specific gravities.

Specific gravity of solution	Percent of sulfuric acid in solution	Approximate relative humidity percent
1.00	H_2O	100
1.05	7.37	97.5
1.09	12.99	94.8
1.12	17.01	92.3
1.14	19.61	89.9
1.18	24.76	84.0
1.20	27.32	80.5
1.23	31.11	74.6
1.25	33.43	70.4
1.27	35.71	65.5
1.29	38.03	60.7
1.30	39.19	58.3
1.344	44.0	49.0
1.361	46.0	45.0
1.438	54.0	29.5
1.479	58.0	21.5
1.524	62.0	15.5
1.569	66.0	10.5
1.639	72.0	6.0
1.710	78.0	3.0

Source: Curtis (1915).

Oxley (1948) found the water content of grain, in mass or large amounts, to be 10.7 percent to 13.4 percent at 50 percent relative humidity. However, with small amounts of grain (10 to 200 grams) the water content is much less at 50 percent relative humidity. The specific moisture content at which a certain relative humidity would hold small samples of wheat was found in the following manner: Two battery jars were set up at approximately 49 percent and 75 percent relative humidity. Samples of 155 grams of wheat in pint jars were placed in each humidifier. The moisture content of this grain, when placed in the large containers, was 11.7 percent. The moisture reading of these samples was taken every two days. In about ten days the readings begin to level off; that is, they begin to remain the same or very nearly so. The grain in the humidifier of 49 percent relative humidity leveled off at about 9 percent moisture content and the grain in the humidifier of 75 percent relative humidity at 12.2 (± 0.1 percent) moisture content. Water was then added in small amounts to the solution in the 49 percent jar until the grain reached a moisture content of 10.2 (± 0.1 percent). In using this trial and error method the following data were gathered:

Relative humidity %	Moisture content of grain %	Specific gravity of acid solution
60 ± 2	10.2 ± 0.1	1.29
75 ± 2	12.2 ± 0.1	1.23
90 ± 2	14.2 ± 0.1	1.14

Only a small amount of acid solution was required to maintain a constant humidity within a battery jar. Never was more than 850 milliliters required for one jar. The depth of this amount of this amount of solution, within the container, was about one and one-half inches. The specific gravity of the solution was measured with a Baume scale hydrometer. The humidity within the humidifier was measured with a hair humidity gauge, accurate within 2 percent.

Temperature Control

The humidifiers were kept in a well insulated constant temperature room under conditions of 80° F. (± 1° F.) and a relative humidity of 50 percent to 60 percent. The temperature in the room was thermostatically controlled by means of a Frigidaire room air conditioner and an electric heater.

Special Apparatus

Moisture Tester. The Steinlite Electric Moisture Tester, Series S, was used for all moisture testing of the wheat for this investigation.

Scales. All weighing was done on a Torsion Prescription Balance, accurate to .01 gram.

Testing Jars. Two ounce glass jars were used as testing jars in this experiment. Twenty grams of wheat approximately half filled one of these jars.

METHODS

Technique in Preparing and Infesting the Wheat

According to Boyce (1946), there may be 32 pairs or 64 beetles in 20 grams of flour before there is much overcrowding. For this reason, it was decided that 20 grams would constitute a convenient size wheat sample; though it is recognized that a 20-gram wheat sample and a 20-gram flour sample do not constitute the same environment. Each sample was in turn infested with 50 insects. The grain was thoroughly cleaned with a sieve and then each cracked kernel was carefully picked out. Only whole kernels were used in this test. The wheat was then weighed out into 20-gram lots and each lot placed in a two-ounce jar. Seventeen of these samples were placed in one humidifier along with one 155-gram sample of wheat which was used for a moisture check. These 17 samples were weighed every five days and the moisture content was taken every two days. The wheat gained or lost in moisture content according to the humidity within the humidifier. When the samples were reweighed, at the end of each five-day interval, wheat was added to or removed from each sample to maintain the 20-gram sample. Within ten days the wheat would begin to level off in moisture content and at the end of approximately three weeks the moisture content was stabilized. However, over an extended period of time (six weeks to three months) the weight of 20 grams of wheat would usually gain or lose from 0.01 to 0.02 of a gram with the humidity within the container remaining the same. In other words considerable time was required for the grain to completely stabilize. For this reason two of the original 17, 20-gram samples were maintained as weight-control samples along with the 155-gram moisture check sample. At the end of three weeks, or after the grain had reached a moisture content in equilibrium with the humidity, the 17 samples were reweighed and 15 of them were infested.

It was found advantageous to sift the 6 to 15 day old beetles into a large pan. As the insects migrated toward the walls of the pan, they were collected with an aspirator. The beetles were collected in groups of 50 individuals at a time for 15 times. Each 50-beetle group was double checked for accurate count and then placed in a 20-gram wheat sample. After 15 of the samples had been infested, they were placed in the humidifier along with the two weight-control samples and the moisture-check sample.

Length of Infestation Periods

The infestation periods of the wheat samples were two months, four months and six months. Five of the samples were removed from the humidifier and examined at the end of two months, five more at the end of four months and the remaining five at the end of six months. The two weight-control samples were weighed and the moisture content of the 155-gram sample was taken at weekly intervals during the six months' period. With a check such as this, the acid solution within the humidifier could easily have been strengthened or weakened had the wheat suddenly gained or lost a large amount of moisture.

Determining the Weight Loss of the Wheat

At the end of each infestation period, when five of the infested samples were examined, the insects were first separated from the wheat. This was done with the use of a 10 mesh screen sieve. The contents of the sample jar were dumped into the sieve and the sample jar was cleaned out with a small camel hair brush. The brush was employed for the purpose of removing the waste dust that adhered to the bottom and sides of the jar. The contents were then sifted with the insects and dust falling into a pan and the wheat remaining in the sieve. The wheat was then weighed and this weight subtracted from the weight of the control samples which were weighed as soon as they were removed from the humidifying chamber. By the use of this method, gain or loss in the weight of the wheat was known and the weight loss could be more accurately determined.

It was found that the wheat did not lose weight immediately after removal from the humidifier or through sifting. This was shown by removing one of the weight control samples from the humidifier and allowing it to remain at a much lower humidity for a period of two hours. At the end of this time the sample was weighed and the weight recorded. The sample was then returned to the chamber and allowed to remain for three days. After the completion of this period the sample was removed and weighed as soon as possible. This weight and the weight which was obtained three days previous were identical. This procedure was repeated three times with the same results.

The insects were separated from the waste or dust by means of a 100 mesh screen sieve. In this way the young larvae were easily removed from the dust. The dust was then brushed from the pan onto a small piece of paper and weighed.

Separating and Counting the Insects

The insects, after being separated from the dust, were put into a small pie pan. As the beetles migrated to the edge of the pan, they were raked over the side with a brush into another pan and counted. The dead adults were removed from the first pan and counted. The larvae and pupae were transferred to a petri dish and placed under the Dazor lamp. The pupae were counted and removed from the petri dish. After counting the larvae, an estimate was made of their different instars. The author made no attempt to measure the head capsules of these larvae to determine the different instars. This estimation was made by comparing the sizes of the larvae.

RESULTS

Working under the laboratory conditions as already described with adults of the flour beetles, Tribolium confusum and _T. castaneum_, this investigation was designed to determine the weight loss of whole kernel wheat and also the ability of these insects to reproduce on whole kernel wheat. This experiment was carried out on 20-gram lots of wheat with moisture contents of 10.2 percent, 12.2 percent and 14.2 percent. Each lot was infested with 50 adult beetles with infestation periods of 60 days, 120 days and 180 days respectively. The results of five replications in which the two species of _Tribolium_ are confined to wheat under the above conditions are presented in Tables 2 to 31 (_confusum_

Tables 2 to 17; castaneum Tables 18 to 31.)

The weight loss as stated in this thesis is figured on the basis of the loss or damage to the grain samples with the waste and feces removed. The difference in weight between the weight loss of the grain and the weight of the dust might be considered in part the metabolic loss. However, the metabolic loss was not considered in this experiment, only the gross weight loss to the wheat.

It was of interest to note the way in which the wheat kernels were attacked by the beetles. The only successful attacks were made at the end of the kernel containing the embryo. No grains were found in which the damage had started from the other end. This is in accordance with the experience of Birch (1947). After the grain embryo was removed, feeding proceeded toward the other end of the kernel. A few of the grains were almost destroyed -- only a mere shell was left. About one-third of the kernels were damaged at each of the three different moisture contents. However, the wheat with the highest amount of water had more grain shells or was damaged the most. That is, the wheat with a moisture content of 10.2 percent was not damaged as much (did not have as many shells) as the wheat with a moisture content of 12.2 percent even though approximately one-third of the kernels had been attacked and damaged in each case. This was true in comparing the 12.2 percent wheat with the 14.2 percent. Illustrations of the grain damage, the dust from the damaged grain, and the insects and their progeny after infesting the wheat during the different periods of time are shown in Figs. 1 to 45.

Table 2. Extent of damage to 20 grams of whole kernel wheat with a moisture content of 10.2 percent by 50 _T. confusum_ and their progeny when confined for 60 days.

Sample no.	Weight of control, g	Weight of infested sample with insects and dust removed, g	Weight loss, g	Weight of dust, g
1	20	19.76	0.24	0.16
2	20	19.74	0.26	0.18
3	20	19.73	0.27	0.17
4	20	19.76	0.24	0.15
5	20	19.75	0.25	0.17
Average	-	-	0.25	0.17

Table 3. Extent of reproduction of 50 _T. confusum_ when confined for 60 days to 20 grams of whole kernel wheat with a moisture content of 10.2 percent.

Sample no.	No. larvae	No. pupae	New emerg. adults	No. dead adults	No. increase
1	3	0	0	39	3
2	4	0	0	37	4
3	9	0	0	29	9
4	5	0	0	37	5
5	6	0	0	33	6
Average	5.4	0	0	35	5.4

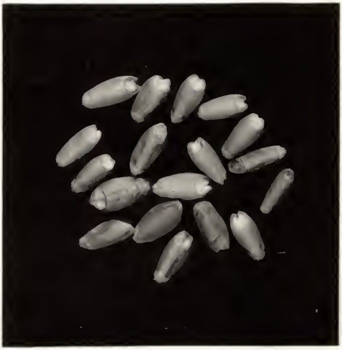


Fig. 1. Damage caused to whole kernel wheat with a moisture content of 10.2 percent by adult T. confusum and their progeny over an infestation period of 60 days.

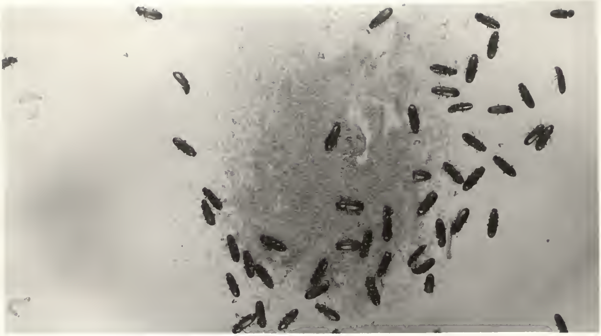


Fig. 2. Adult T. confusum and their progeny after 60 days confinement to 20 grams of whole kernel wheat with a moisture content of 10.2 percent.

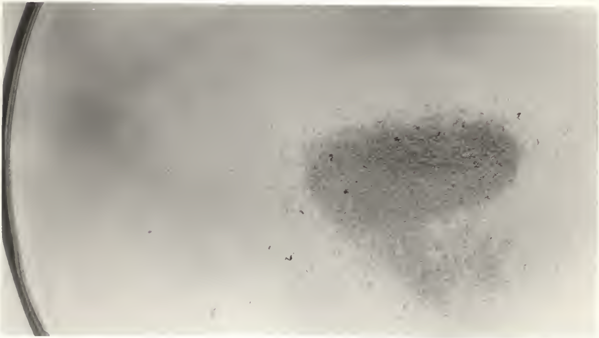


Fig. 3. Dust from 20 grams of whole kernel wheat with a moisture content of 10.2 percent caused by T. confusum and their progeny during 60 days infestation.

Table 4. Extent of damage to 20 grams of whole kernel wheat with a moisture content of 12.2 percent by 50 _T. confusum_ and their progeny when confined for 60 days.

Sample no.	Weight of control, g	Weight of infested sample with insects removed, g	Weight loss, g	Weight of dust, g
1	20.01	19.56	0.45	0.24
2	20.01	19.65	0.36	0.18
3	20.01	19.52	0.49	0.26
4	20.01	19.59	0.42	0.22
5	20.01	19.62	0.39	0.23
Average	-	-	0.42	0.23

Table 5. Extent of reproduction of 50 _T. confusum_ when confined for 60 days to 20 grams of whole kernel wheat with a moisture content of 12.2 percent.

Sample no.	No. larvae	No. pupae	New emerg. adults	No. dead adults	No. increase
1	21	9	5	14	35
2	12	2	2	6	16
3	26	5	6	2	37
4	23	7	4	9	34
5	19	4	5	10	28
Average	20.2	5.4	4.4	8.2	30

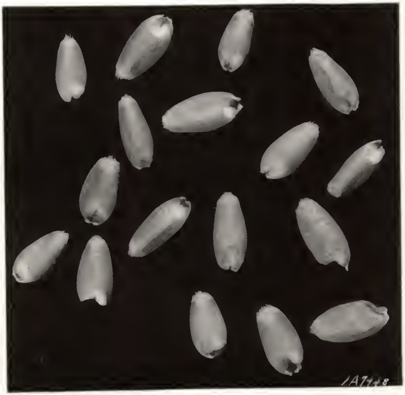


Fig. 4. Damage caused to whole kernel wheat with a moisture content of 12.2 percent by adult T. confusum and their progeny over an infestation period of 60 days.

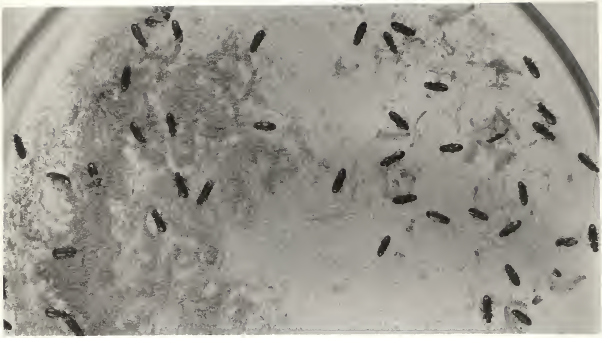


Fig. 5. Adult T. confusum and their progeny after 60 days confinement to 20 grams of whole kernel wheat with a moisture content of 12.2 percent.

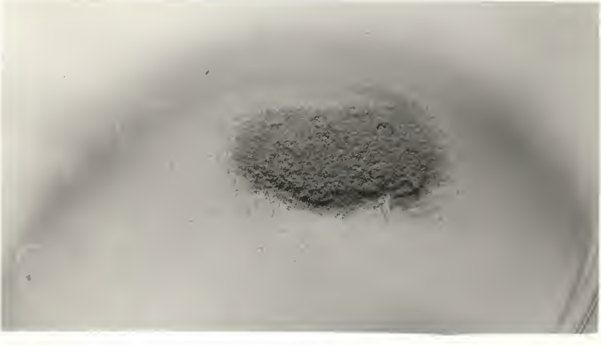


Fig. 6. Dust from 20 grams of whole kernel wheat with a moisture content of 12.2 percent caused by T. confusum and their progeny during 60 days infestation.

Table 6. Extent of damage to 20 grams of whole kernel wheat with a moisture content of 14.2 percent by 50 *T. confusum* and their progeny when confined for 60 days.

Sample no.	Weight of control, g	Weight of infested samples with insects removed, g	Weight loss, g	Weight of dust, g
1	20.02	19.42	0.60	0.31
2	20.02	19.31	0.71	0.33
3	20.02	19.36	0.66	0.30
4	20.02	19.34	0.68	0.32
5	20.02	19.39	0.63	0.30
Average	-	-	0.66	0.32

Table 7. Extent of reproduction of 50 *T. confusum* when confined for 60 days to 20 grams of whole kernel wheat with a moisture content of 14.2 percent.

Sample no.	No. larvae	No. pupae	New emerg. adults	No. dead adults	No. increase
1	13	9	16	2	38
2	16	12	23	1	51
3	12	7	26	1	45
4	12	8	21	1	41
5	11	9	19	2	39
Average	12.8	9	21	1.4	42.8

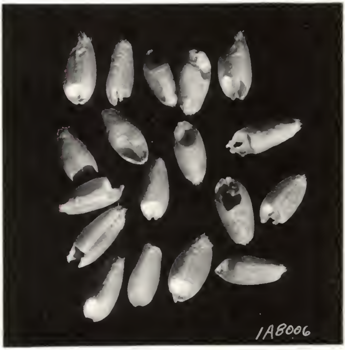


Fig. 7. Damage caused to whole kernel wheat with a moisture content of 14.2 percent by adult T. confusum and their progeny over an infestation period of 60 days.

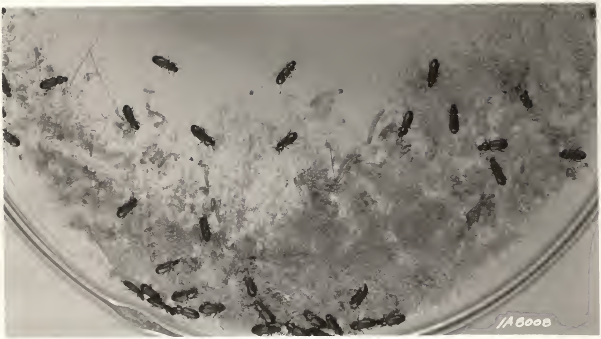


Fig. 8. Adult T. confusum and their progeny after 60 days confinement to 20 grams of whole kernel wheat with a moisture content of 14.2 percent.

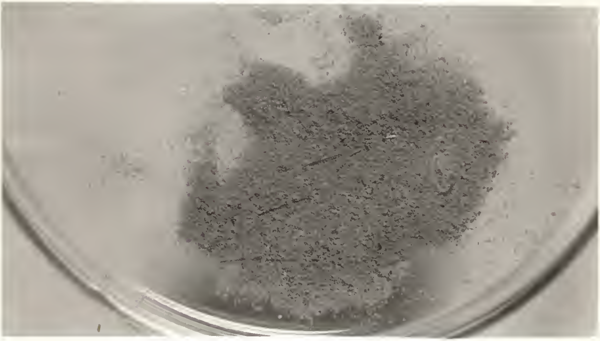


Fig. 9. Dust from 20 grams of whole kernel wheat with a moisture content of 14.2 percent caused by T. confusum and their progeny during 60 days infestation.

Table 8. Extent of damage to 20 grams of whole kernel wheat with a moisture content of 10.2 percent by 50 *T. confusum* and their progeny when confined for 120 days.

Sample no.	Weight of control, g	Weight of infested sample with insects removed, g	Weight loss, g	Weight of dust, g
1	20	19.65	0.35	0.22
2	20	19.63	0.37	0.23
3	20	19.68	0.32	0.19
4	20	19.67	0.33	0.21
5	20	19.64	0.36	0.21
Average	-	-	0.35	0.21

Table 9. Extent of reproduction of 50 *T. confusum* when confined for 120 days to 20 grams of whole kernel wheat with a moisture content of 10.2 percent.

Sample no.	No. larvae	No. pupae	New emerg. adults	No. dead adults	No. increase
1	0	0	2	52	2
2	0	0	3	53	3
3	0	0	2	52	2
4	0	0	1	51	1
5	0	0	3	53	3
Average	0	0	2.2	52.2	2.2

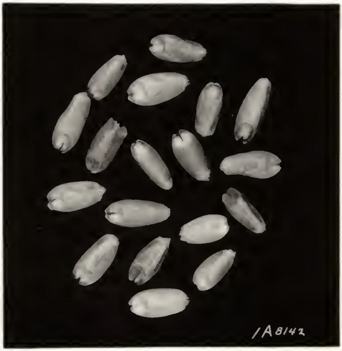


Fig. 10. Damage caused to whole kernel wheat with a moisture content of 10.2 percent by adult *T. confusum* and their progeny over an infestation period of 120 days.

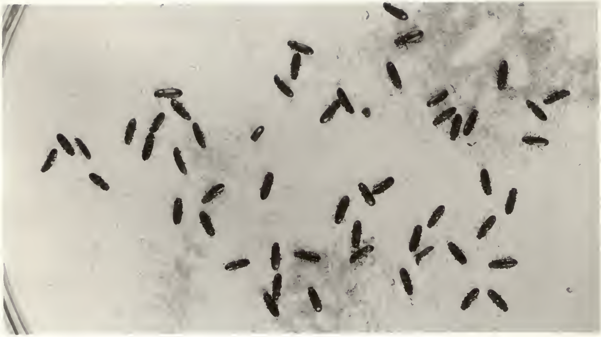


Fig. 11. Adult T. confusum and their progeny after 120 days confinement to 20 grams of whole kernel wheat with a moisture content of 10.2 percent.

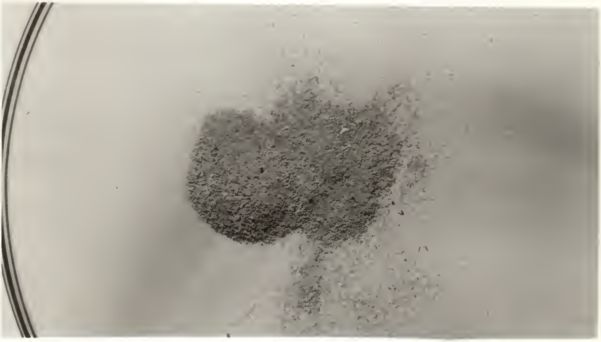


Fig. 12. Dust from 20 grams of whole kernel wheat with a moisture content of 10.2 percent caused by T. confusum and their progeny during 120 days infestation.

Table 10. Extent of damage to 20 grams of whole kernel wheat with a moisture content of 12.2 percent by 50 _T. confusum_ and their progeny when confined for 120 days.

Sample no.	Weight of control, g	Weight of infested sample with insects removed, g	Weight loss, g	Weight of dust, g
1	20.01	18.60	1.41	0.43
2	20.01	18.72	1.29	0.38
3	20.01	18.93	1.08	0.32
4	20.01	18.78	1.23	0.36
5	20.01	18.85	1.16	0.33
Average	-	-	1.23	0.36

Table 11. Extent of reproduction of 50 _T. confusum_ when confined for 120 days to 20 grams of whole kernel wheat with a moisture content of 12.2 percent.

Sample no.	No. larvae	No. pupae	New emerg. adults	No. dead adults	No. increase
1	31	4	43	34	78
2	28	3	37	26	68
3	26	5	32	40	63
4	25	4	35	29	64
5	27	3	33	36	63
Average	27.4	3.8	36	33	67.2

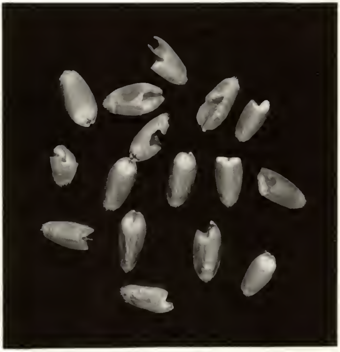


Fig. 13. Damage caused to whole kernel wheat with a moisture content of 12.2 percent by adult T. confusum and their progeny over an infestation period of 120 days.

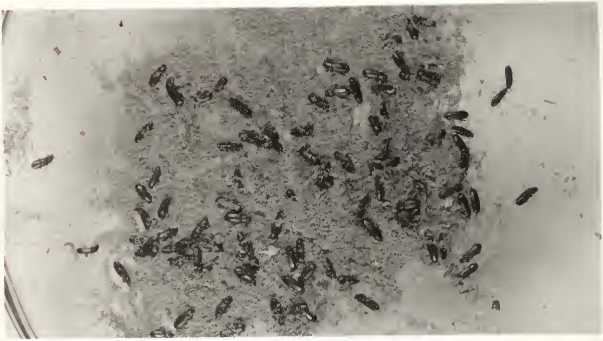


Fig. 14. Adult T. confusum and their progeny after 120 days confinement to 20 grams of whole kernel wheat with a moisture content of 12.2 percent.

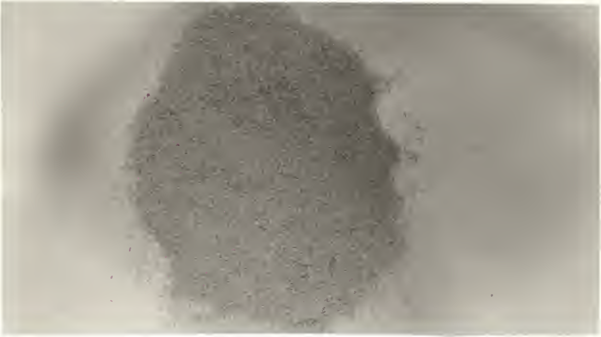


Fig. 15. Dust from 20 grams of whole kernel wheat with a moisture content of 12.2 percent caused by T. confusum and their progeny during 120 days infestation.

Table 12. Extent of damage to 20 grams of whole kernel wheat with a moisture content of 14.2 percent by 50 *T. confusum* and their progeny when confined for 120 days.

Sample no.	Weight of control, g	Weight of infested sample with insects removed, g	Weight loss, g	Weight of dust, g
1	20.02	18.50	1.52	0.56
2	20.02	18.29	1.73	0.63
3	20.02	18.24	1.78	0.66
4	20.02	18.38	1.64	0.59
5	20.02	18.33	1.69	0.60
Average	-	-	1.67	0.61

Table 13. Extent of reproduction of 50 *T. confusum* when confined for 120 days to 20 grams of whole kernel wheat with a moisture content of 14.2 percent.

Sample no.	No. larvae	No. pupae	New emerg. adults	No. dead adults	No. increase
1	14	7	56	3	77
2	17	11	63	2	91
3	16	12	69	2	97
4	15	10	59	3	84
5	16	8	58	1	82
Average	15.6	9.6	61	2.2	86.2

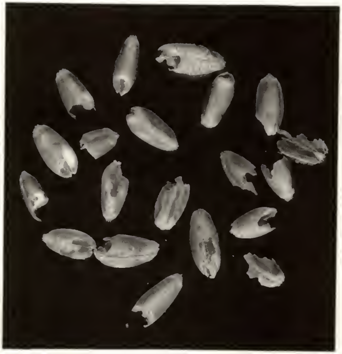


Fig. 16. Damage caused to whole kernel wheat with a moisture content of 14.2 percent by adult T. confusum and their progeny over an infestation period of 120 days.

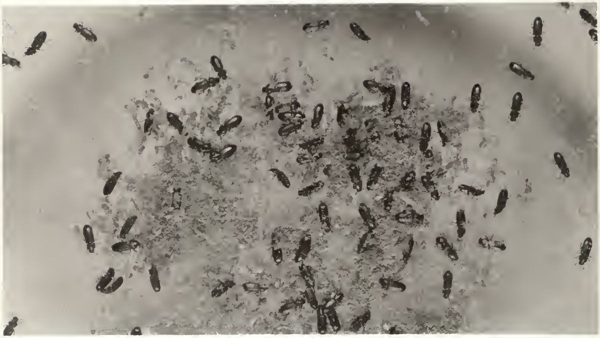


Fig. 17. Adult T. confusum and their progeny after 120 days confinement to 20 grams of whole kernel wheat with a moisture content of 14.2 percent.

Fig. 18. Dust from 20 grams of whole kernel wheat with a moisture content of 14.2 percent caused by T. confusum and their progeny during 120 days infestation.

Table 14. Extent of damage to 20 grams of whole kernel wheat with a moisture content of 12.2 percent by 50 *T. confusum* and their progeny when confined for 180 days.

Sample no.	Weight of control, g	Weight of infested sample with insects removed, g	Weight loss, g	Weight of dust, g
1	20.01	18.39	1.62	0.57
2	20.01	18.14	1.87	0.71
3	20.01	18.30	1.71	0.68
4	20.01	18.32	1.69	0.66
5	20.01	18.25	1.76	0.70
Average	-	-	1.73	0.66

Table 15. Extent of reproduction of 50 *T. confusum* when confined for 180 days to 20 grams of whole kernel wheat with a moisture content of 12.2 percent.

Sample no.	No. larvae	No. pupae	New emerg. adults	No. dead adults	No. increase
1	34	2	46	38	82
2	33	4	56	41	93
3	28	3	48	44	79
4	30	2	49	42	81
5	32	3	52	45	87
Average	31.4	2.8	50.2	42	84.4

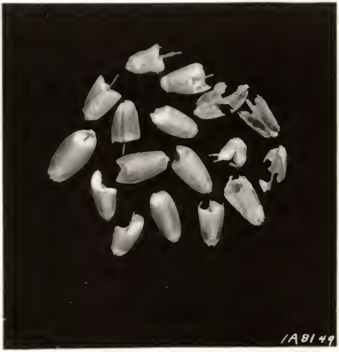


Fig. 19. Damage caused to whole kernel wheat with a moisture content of 12.2 percent by T. confusum and their progeny over an infestation period of 180 days.

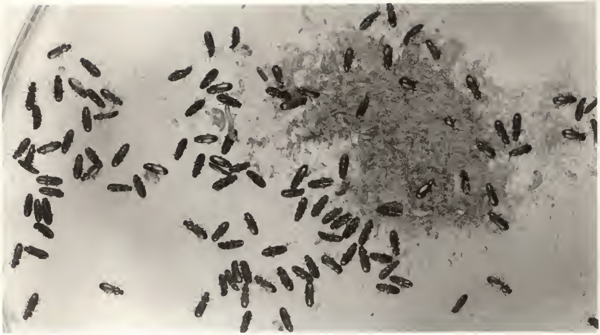


Fig. 20. Adult T. confusum and their progeny after 180 days confinement of 20 grams of whole kernel wheat with a moisture content of 12.2 percent.

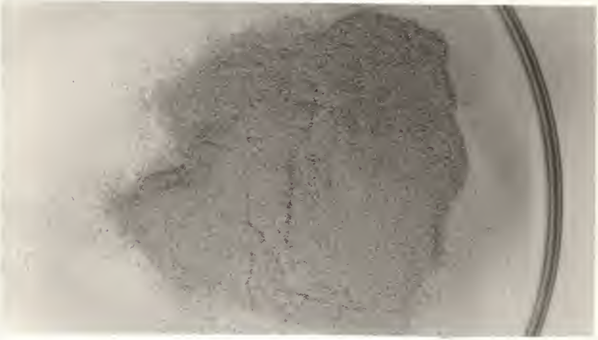


Fig. 21. Dust from 20 grams of whole kernel wheat with a moisture content of 12.2 percent caused by T. confusum and their progeny during 180 days infestation.

Table 16. Extent of damage to 20 grams of whole kernel wheat with a moisture content of 14.2 percent by 50 T. confusum and their progeny when confined for 180 days.

Sample no.	Weight of control, g	Weight of infested sample with insects removed, g	Weight loss, g	Weight of dust, g
1	20.02	17.74	2.28	0.78
2	20.02	18.09	1.93	0.69
3	20.02	17.98	2.04	0.73
4	20.02	17.65	2.37	0.86
5	20.02	17.84	2.18	0.83
Average	-	-	2.16	0.78

Table 17. Extent of reproduction of 50 T. confusum when confined for 180 days to 20 grams of whole kernel wheat with a moisture content of 14.2 percent.

Sample no.	No. larvae	No. pupae	New emerg. adults	No. dead adults	No. increase
1	18	4	67	3	89
2	19	3	60	2	82
3	14	3	61	3	78
4	21	5	72	2	98
5	20	2	66	4	88
Average	18.4	3.4	65.2	2.8	87

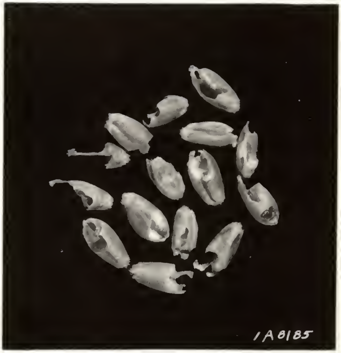


Fig. 22. Damage caused to whole kernel wheat with a moisture content of 14.2 percent by adult T. confusum and their progeny over an infestation period of 180 days.

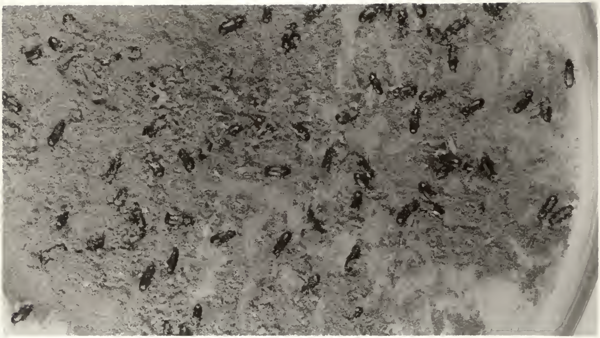


Fig. 23. Adult T. confusum and their progeny after 180 days confinement to 20 grams of whole kernel wheat with a moisture content of 14.2 percent.

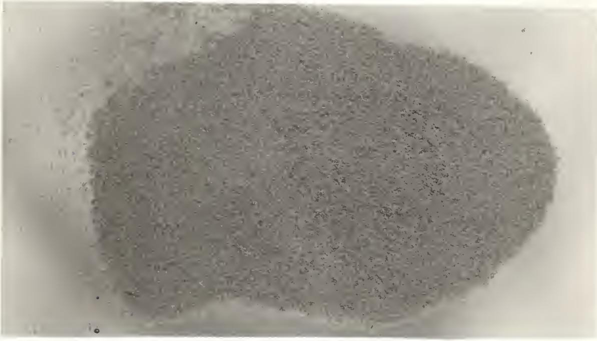


Fig. 24. Dust from 20 grams of whole kernel wheat with a moisture content of 14.2 percent caused by T. confusum and their progeny during 180 days infestation.

Table 18. Extent of damage to 20 grams of whole kernel wheat with a moisture content of 10.2 percent by 50 *T. castaneum* and their progeny when confined for 60 days.

Sample no.	Weight of control, g	Weight of infested sample with insects removed, g	Weight loss, g	Weight of dust, g
1	20	19.83	0.17	0.08
2	20	19.81	0.19	0.09
3	20	19.81	0.19	0.10
4	20	19.82	0.18	0.08
5	20	19.84	0.16	0.07
Average	-	-	0.18	0.08

Table 19. Extent of reproduction of 50 *T. castaneum* when confined for 60 days to 20 grams of whole kernel wheat with a moisture content of 10.2 percent.

Sample no.	No. larvae	No. pupae	New emerg. adults	No. dead adults	No. increase
1	0	0	0	50	0
2	0	0	0	50	0
3	0	0	0	50	0
4	0	0	0	50	0
5	0	0	0	50	0
Average	0	0	0	50	0

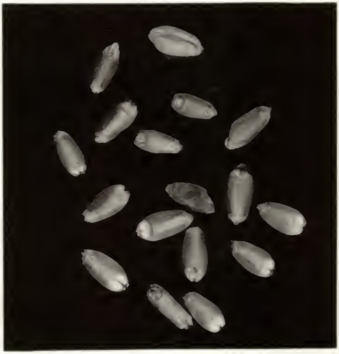


Fig. 25. Damage caused to whole kernel wheat with a moisture content of 10.2 percent by adult T. castaneum over an infestation period of 60 days.

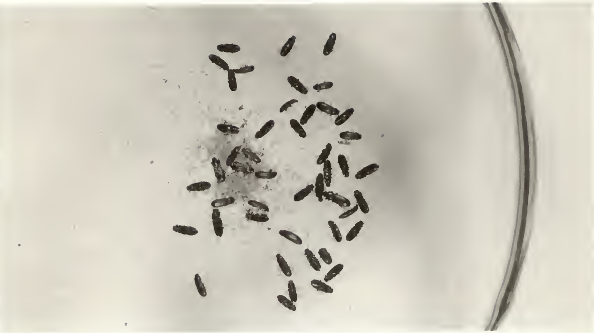


Fig. 26. Adult T. castaneum, without progeny, after 60 days confinement to 20 grams of whole kernel wheat with a moisture content of 10.2 percent.

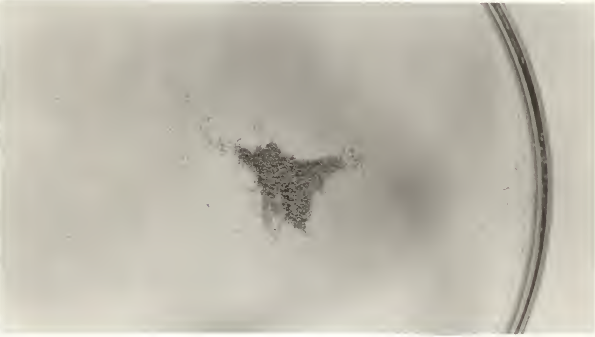


Fig. 27. Dust from 20 grams of whole kernel wheat with a moisture content of 10.2 percent caused by T. castaneum during a period of 60 days infestation.

Table 20. Extent of damage to 20 grams of whole kernel wheat with a moisture content of 12.2 percent by 50 _T. castaneum_ and their progeny when confined for 60 days.

Sample no.	Weight of control, g	Weight of infested sample with insects removed, g	Weight loss, g	Weight of dust, g
1	20.01	19.72	0.29	0.21
2	20.01	19.87	0.23	0.16
3	20.01	19.71	0.30	0.23
4	20.01	19.76	0.25	0.17
5	20.01	19.74	0.27	0.19
Average	-	-	0.27	0.19

Table 21. Extent of reproduction of 50 _T. castaneum_ when confined for 60 days to 20 grams of whole kernel wheat with a moisture content of 12.2 percent.

Sample no.	No. larvae	No. pupae	New emerg. adults	No. dead adults	No. increase
1	7	3	1	43	11
2	6	1	0	45	7
3	6	2	0	41	8
4	5	0	0	44	5
5	6	0	1	42	7
Average	6	1.2	0.4	43	7.6

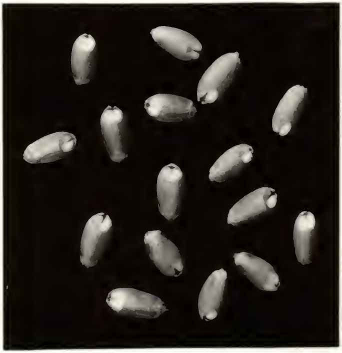


Fig. 28. Damage caused to whole kernel wheat with a moisture content of 12.2 percent by adult T. castaneum and their progeny over an infestation period of 60 days.

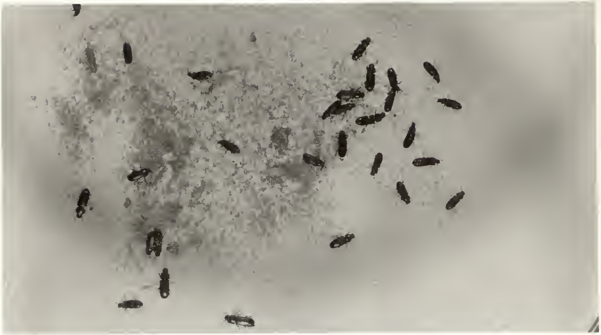


Fig. 29. Adult T. castaneum and their progeny after 60 days confinement to 20 grams of whole kernel wheat with a moisture content of 12.2 percent.

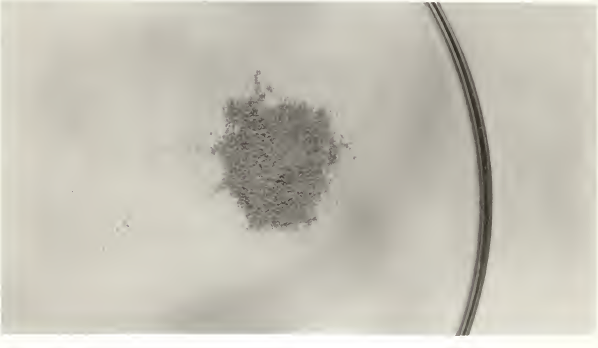


Fig. 30. Dust from 20 grams of whole kernel wheat with a moisture content of 12.2 percent caused by T. castaneum and their progeny during 60 days infestation.

Table 22. Extent of damage to 20 grams of whole kernel wheat with a moisture content of 14.2 percent by 50 *T. castaneum* and their progeny when confined for 60 days.

Sample no.	Weight of control, g	Weight of infested sample with insects removed, g	Weight loss, g	Weight of dust, g
1	20.02	19.56	0.46	0.27
2	20.02	19.51	0.51	0.26
3	20.02	19.53	0.49	0.25
4	20.02	19.49	0.53	0.27
5	20.02	19.55	0.47	0.25
Average	-	-	0.49	0.26

Table 23. Extent of reproduction of 50 *T. castaneum* when confined for 60 days to 20 grams of whole kernel wheat with a moisture content of 14.2 percent.

Sample no.	No. larvae	No. pupae	New emerg. adults	No. dead adults	No. increase
1	5	0	6	11	11
2	6	3	8	8	17
3	5	1	6	10	12
4	7	3	9	5	19
5	6	2	6	9	14
Average	5.8	1.8	7	8.6	14.6

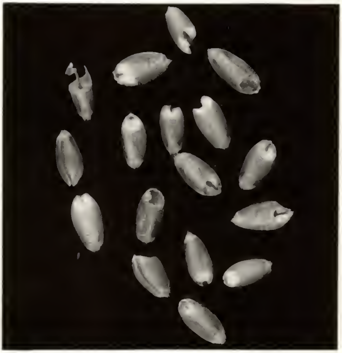


Fig. 31. Damage caused to whole kernel wheat with a moisture content of 14.2 percent by adult T. castaneum and their progeny over an infestation period of 60 days.

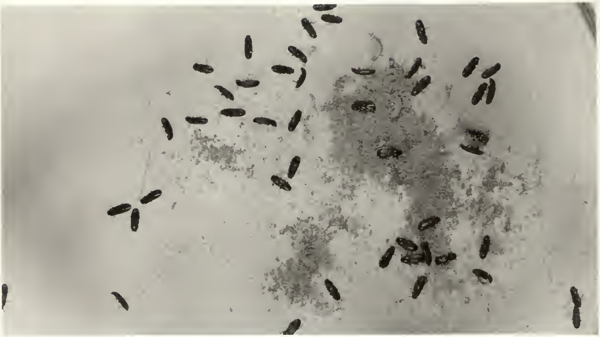


Fig. 32. Adult T. castaneum and their progeny after 60 days confinement to 20 grams of whole kernel wheat with a moisture content of 14.2 percent.

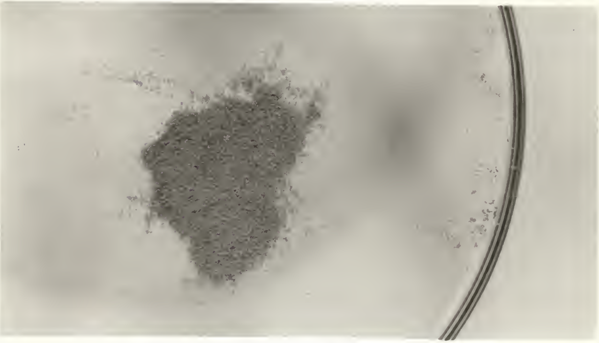


Fig. 33. Dust from 20 grams of whole kernel wheat with a moisture content of 14.2 percent caused by T. castaneum and their progeny during 60 days infestation.

Table 24. Extent of damage to 20 grams of whole kernel wheat with a moisture content of 12.2 percent by 50 *T. castaneum* and their progeny when confined for 120 days.

Sample no.	Weight of control, g	Weight of infested sample with insects removed, g	Weight loss, g	Weight of dust, g
1	20.01	19.63	0.38	0.26
2	20.01	19.67	0.34	0.22
3	20.01	19.66	0.35	0.24
4	20.01	19.70	0.31	0.20
5	20.01	19.68	0.33	0.21
Average	-	-	0.34	0.23

Table 25. Extent of reproduction of 50 *T. castaneum* when confined for 120 days to 20 grams of whole kernel wheat with a moisture content of 12.2 percent.

Sample no.	No. larvae	No. pupae	New emerg. adults	No. dead adults	No. increase
1	15	3	5	49	23
2	8	2	4	47	14
3	9	2	3	45	14
4	7	1	4	48	12
5	8	2	3	46	13
Average	9.4	2	3.8	47	15.2

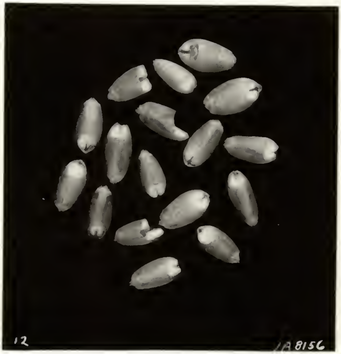


Fig. 34. Damage caused to whole kernel wheat with a moisture content of 12.2 percent by adult T. castaneum and their progeny over an infestation period of 120 days.

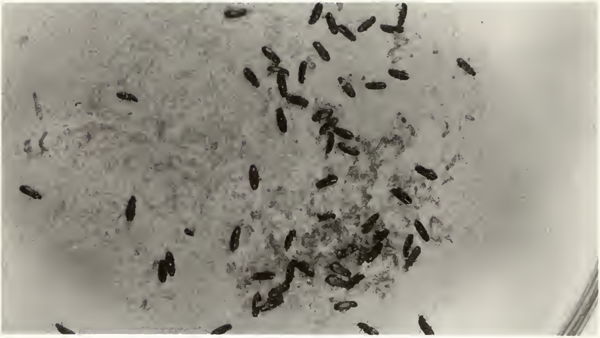


Fig. 35. Adult T. castaneum and their progeny after 120 days confinement to 20 grams of whole kernel wheat with a moisture content of 12.2 percent.

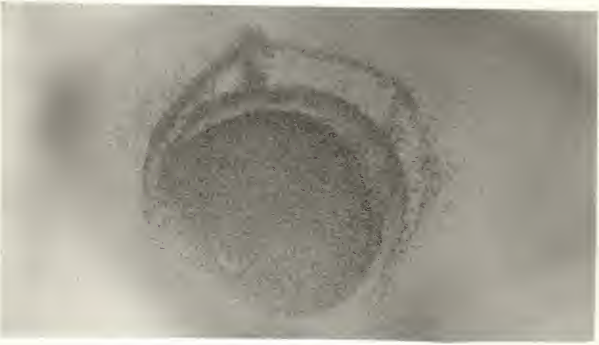


Fig. 36. Dust from 20 grams of whole kernel wheat with a moisture content of 12.2 percent caused by T. castaneum and their progeny during 120 days infestation.

Table 26. Extent of damage to 20 grams of whole kernel wheat with a moisture content of 14.2 percent by 50 *T. castaneum* and their progeny when confined for 120 days.

Sample no.	Weight of control, g	Weight of infested sample with insects removed, g	Weight loss, g	Weight of dust, g
1	20.02	19.40	0.62	0.30
2	20.02	19.45	0.57	0.28
3	20.02	19.43	0.59	0.29
4	20.02	19.42	0.60	0.27
5	20.02	19.47	0.55	0.25
Average	-	-	0.59	0.28

Table 27. Extent of reproduction of 50 *T. castaneum* when confined for 120 days to 20 grams of whole kernel wheat with a moisture content of 14.2 percent.

Sample no.	No. larvae	No. pupae	New emerg. adults	No. dead adults	No. increase
1	8	3	10	12	21
2	6	2	9	13	17
3	9	3	13	10	25
4	7	3	8	9	18
5	5	0	7	16	12
Average	7	2.2	9.4	12	18.6

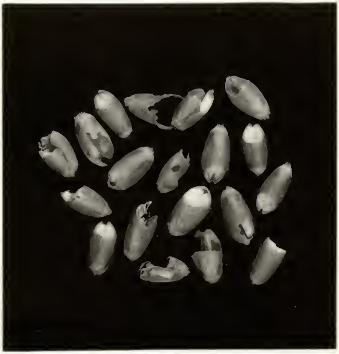


Fig. 37. Damage caused to whole kernel wheat with a moisture content of 14.2 percent by adult T. castaneum and their progeny over an infestation period of 120 days.

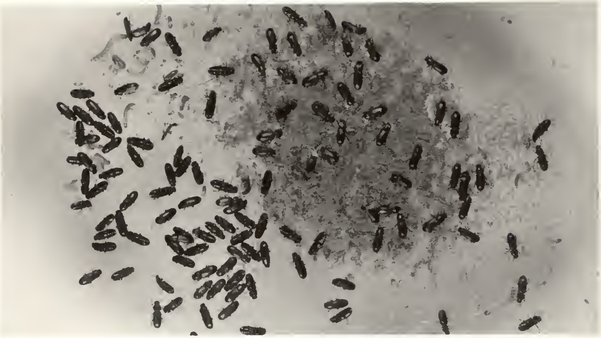


Fig. 38. Adult T. castaneum and their progeny after 120 days confinement to 20 grams of whole kernel wheat with a moisture content of 14.2 percent.

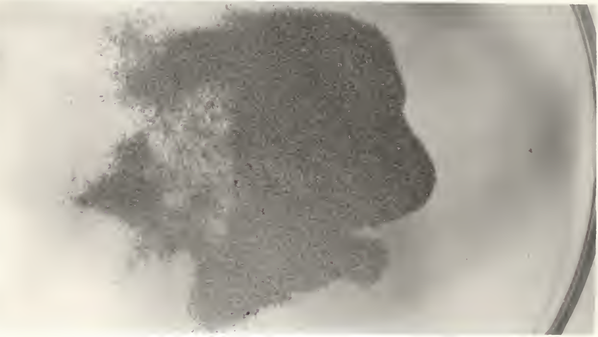


Fig. 39. Dust from 20 grams of whole kernel wheat with a moisture content of 14.2 percent caused by T. castaneum and their progeny during 120 days infestation.

Table 28. Extent of damage to 20 grams of whole kernel wheat with a moisture content of 12.2 percent by 50 *T. castaneum* and their progeny when confined for 180 days.

Sample no.	Weight of control, g	Weight of infested sample with insects and dust removed, g	Weight loss, g	Weight of dust, g
1	20.01	19.59	0.42	0.29
2	20.01	19.61	0.40	0.27
3	20.01	19.54	0.47	0.32
4	20.01	19.62	0.39	0.26
5	20.01	19.57	0.44	0.29
Average	-	-	0.42	0.29

Table 29. Extent of reproduction of 50 *T. castaneum* when confined for 180 days to 20 grams of whole kernel wheat with a moisture content of 12.2 percent.

Sample no.	No. larvae	No. pupae	New emerg. adults	No. dead adults	No. increase
1	15	1	12	48	28
2	12	1	10	51	23
3	14	2	11	49	27
4	11	0	7	54	18
5	14	2	9	52	25
Average	13.2	1.2	9.8	50.8	24.2

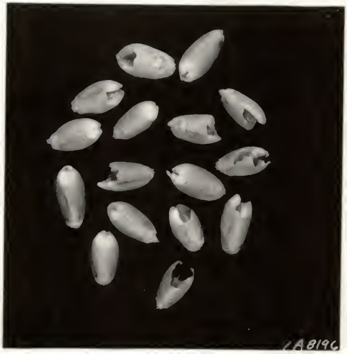


Fig. 40. Damage caused to whole kernel wheat with a moisture content of 12.2 percent by adult T. castaneum and their progeny over an infestation period of 180 days.

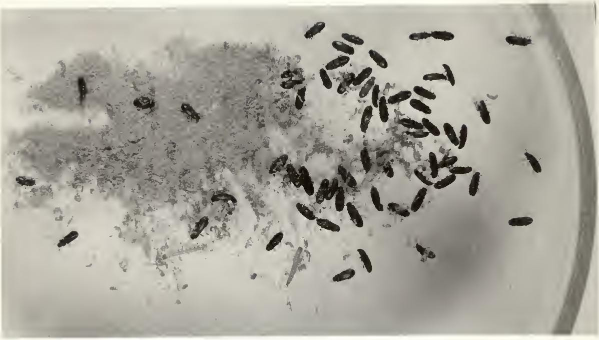


Fig. 41. Adult T. castaneum and their progeny after 180 days confinement to 20 grams of whole kernel wheat with a moisture content of 12.2 percent.

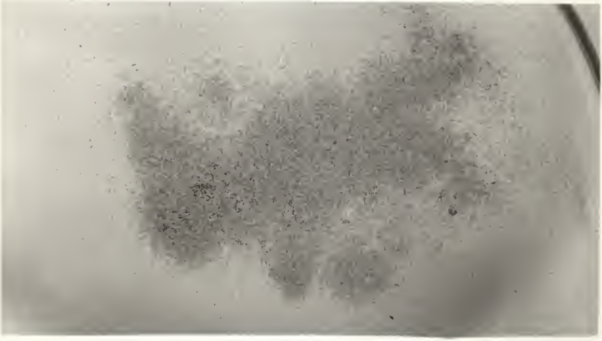


Fig. 42. Dust from 20 grams of whole kernel wheat with a moisture content of 12.2 percent caused by T. castaneum and their progeny during 180 days infestation.

Table 30. Extent of damage to 20 grams of whole kernel wheat with a moisture content of 14.2 percent by 50 *T. castaneum* and their progeny when confined for 180 days.

Sample no.	Weight of control, g	Weight of infested sample with insects and dust removed, g	Weight loss, g	Weight of dust, g
1	20.02	19.23	0.79	0.38
2	20.02	19.26	0.76	0.34
3	20.02	19.27	0.75	0.37
4	20.02	19.33	0.69	0.32
5	20.02	19.25	0.77	0.35
Average	-	-	0.75	0.35

Table 31. Extent of reproduction of 50 *T. castaneum* when confined for 180 days to 20 grams of whole kernel wheat with a moisture content of 14.2 percent.

Sample no.	No. larvae	No. pupae	New emerg. adults	No. dead adults	No. increase
1	13	2	17	21	32
2	11	1	14	29	26
3	10	2	18	26	30
4	9	2	11	33	22
5	12	3	16	19	31
Average	11	2	15.2	25.6	28.2

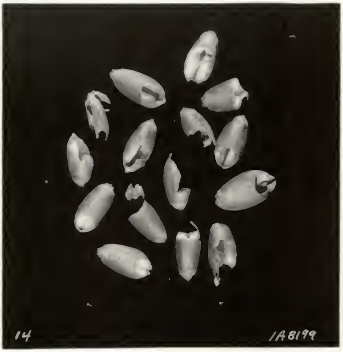


Fig. 43. Damage caused to whole kernel wheat with a moisture content of 14.2 percent by adult T. castaneum and their progeny over an infestation period of 180 days.

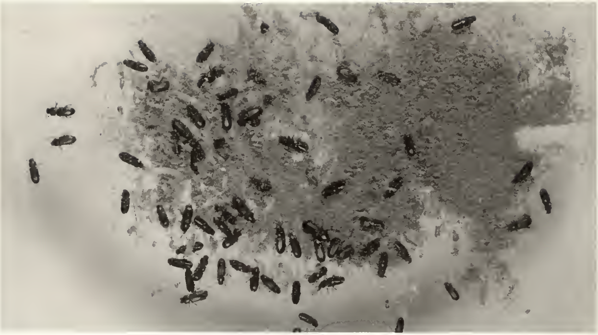


Fig. 44. Adult T. castaneum and their progeny after 180 days confinement to 20 grams of whole kernel wheat with a moisture content of 14.2 percent.

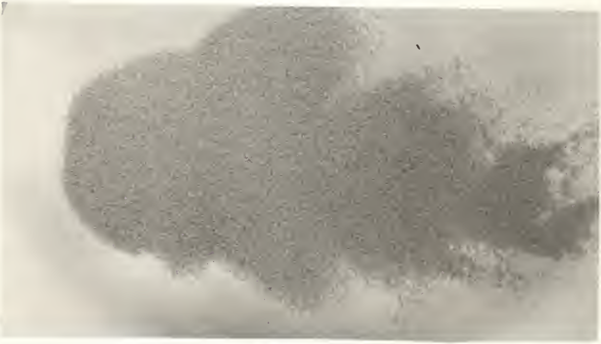


Fig. 45. Dust from 20 grams of whole kernel wheat with a moisture content of 14.2 percent caused by T. castaneum and their progeny during 180 days infestation.

ANALYSIS OF RESULTS

Extent of Damage

By infesting wheat samples of different moisture contents with the same number of adult insects it has been found that the moisture content plays an important part in the extent of damages or weight loss of the wheat. For 20-gram lots of wheat with a moisture content of 10.2 percent and each infested with 50 adult *Tribolium confusum* the average weight loss at the end of 60 days, was 0.25 gram and the average quantity of dust 0.17 gram (Table 2, Figs. 1 and 3). At the end of 120 days the weight loss of five 20-gram samples averaged 0.35 gram and the weight of the dust 0.21 gram by 50 adult beetles and their progeny (Table 8, Figs. 4 and 6). There was complete mortality of these by 120 days. The weight loss by *T. castaneum* to 20-gram lots of wheat under the above conditions averaged 0.18 gram and the weight of the dust 0.08 gram at the end of 60 days as shown in Table 18, Figs. 25 and 27. *Tribolium castaneum* under these conditions showed complete mortality by the end of 60 days.

The average weight loss of the wheat with a moisture content of 12.2 percent, infested with *T. confusum*, was 0.42 gram and the weight of the dust 0.23 gram at the end of 60 days, 1.23 grams and 0.36 gram at the end of 120 days and 1.73 grams and 0.66 gram at the end of 180 days (Tables 4, 10, 14, Figs. 4 and 6, 13 and 15, 19 and 21). For *T. castaneum* at the end of 60 days the damage or loss to the wheat, at 12.2 percent moisture content, averaged 0.27 gram and the dust 0.19 gram, 0.34 gram and 0.23 gram at the end of 120 days and 0.42 gram and 0.29 gram at the end of 180 days as shown in Tables 20, 24, 28, Figs. 28 and 30, 34 and 36, 40 and 42.

The wheat with a moisture content of 14.2 percent and infested with T. confusum showed an average weight loss of 0.66 gram with the average amount of dust weighing 0.32 gram at the end of a 60 day period, 1.67 grams and 0.61 gram at the end of 120 days and 2.16 grams and 0.78 gram after 180 days (Tables 6, 12, 16, Figs. 7 and 9, 16 and 18, 22 and 24). For T. castaneum the average loss for the 20-gram samples of wheat was 0.49 gram and the quantity of dust was 0.26 gram at the end of 60 days, 0.59 gram and 0.28 gram at the end of 120 days and 0.75 gram and 0.35 gram at the end of 180 days (Tables 22, 26, 30, Figs. 31 and 33, 37 and 39, 43 and 45).

From the foregoing section it is evident that the moisture content of the wheat is an important factor in the amount of damage or weight loss of the grain. It is also evident that T. confusum caused appreciably greater damage to the wheat than T. castaneum. These factors are represented graphically in Figs. 46 and 47.

Extent of Reproduction

In 20-gram samples of wheat with a moisture content of 10.2 percent, 50 adult T. confusum produced an average of 5.4 larvae by the end of a 60 day period. No pupae or adults were produced during this time. Thus the average increase for T. confusum at the end of 60 days was 5.4 (Table 3; Fig. 2). At the end of 120 days there were no larvae or pupae, however, an average of 2.2 adults had emerged but were found dead as there was complete mortality of T. confusum by the end of 120 days (Table 9; Fig. 11). Tribolium castaneum in 10.2 percent wheat were all dead without reproduction at the end of 60 days (Table 19, Fig. 26).

The average increase in reproduction for T. confusum in wheat with a moisture content of 12.2 percent was 30 insects at the end of 60 days; 20.2 larvae, 5.4 pupae and 4.4 adults (Table 5, Fig. 5). By the end of 120 days their average increase in reproduction was 27.4 larvae, 3.8 pupae and 36 adults making a total of 67.2 (Table 11, Fig. 14). For T. confusum in wheat with 12.2 percent moisture content the average increase in reproduction at the end of 180 days was 31.4 larvae, 2.8 pupae and 50.2 adults making a total of 84.4 (Table 15, Fig. 20). The average increase in reproduction at the end of 60 days for 50 adult T. castaneum in 20-gram samples of wheat with a moisture content of 12.2 percent was 6 larvae, 1.2 pupae and 0.4 adults making a total of 7.6 (Table 21, Fig. 29). For T. castaneum at the end of 120 days the average was 9.4 larvae, 2 pupae and 3.8 adults giving a total of 15.2 (Table 25, Fig. 35). By the end of 180 days their average increase was 13.2 larvae, 1.2 pupae and 9.8 adults making a total of 24.2 (Table 29, Fig. 41).

Fifty adults of T. confusum after being confined for 60 days to 20 grams of wheat with a 14.2 percent moisture content showed an average increase in reproduction of 12.8 larvae, 9 pupae and 21 adults giving a total of 42.8 (Table 7, Fig. 8). After 120 days confinement this same species had an average increase of 15.6 larvae, 9.6 pupae and 61 adults making a total of 86.2 (Table 13, Fig. 17). At the end of 180 days their average increase was 18.4 larvae, 3.4 pupae and 65.2 adults this giving a total of 87 insects (Table 17, Fig. 23). _Tribolium_ _castaneum_ in wheat with a moisture content of 14.2 percent showed an average increase of 5.8 larvae, 1.8 pupae and 7 adults giving a total of 14.6 at the end of 60 days (Table 23, Fig. 32). By the end of 120 days the average increase in reproduction of _T_. _castaneum_ was 7 larvae, 2.2 pupae and 9.4 adults which made a total of 18.6 (Table 26, Fig. 38). After 180 days their average was 11 larvae, 2 pupae and 15.2 adults giving a total of 28.2 (Table 31, Fig. 44). The reproduction is represented graphically in Figs. 48 and 49.

The moisture content of the wheat appeared to be an important factor not only in the weight loss of the grain but also in the extent of reproduction of these insects. It has been shown that _T_. _confusum_ was much more successful in reproduction while living in whole kernel wheat under these conditions than _T_. _castaneum_. In the 10.2 percent wheat there was little reproduction in _T_. _confusum_ and none in T. castaneum. Larvae of _T_. _confusum_ were found after the first 60 days but no pupae. However, after 120 days an average of 2.2 insects had reached the adult stage and died.

In the wheat with a moisture content of 12.2 percent there was an increase of larval population in comparison with the 14.2 percent wheat and a small number of pupae. Upon examining and estimating the different larval instars there seemed to be a preponderance of last instar larvae. There were more of these large larvae of the same size than any of the other smaller instars. Chapman (1918) stated that the life cycle of the beetles reared on different foods, under uniform conditions, may vary in length and that this difference in development is confined largely to the last larval instar. However, in this experiment there was an increase in number of the last larval instar when reared on the same food under different moisture conditions. There was a more equal distribution of the different instars of the larvae in wheat with a 14.2 percent moisture content. Also in the 14.2 percent wheat there were more pupae and less larvae than in the 12.2 percent wheat. This indicates that the beetles developed and emerged faster in the 14.2 percent wheat than in the 12.2 percent wheat.

Mortality

The extent of mortality of the immature stages under the conditions in this experiment is not known because these insects may consume some of their eggs, larvae and pupae, particularly eggs and pupae. The mortality of the adults was determined by counting the dead. These dead insects appeared to be mostly of the original 50 and not of their progeny. In 20-gram wheat samples with a moisture content of 10.2 percent, infested with 50 adult T. confusum, the average number of dead adults was 35 at the end of 60 days (Table 3). By the end of 120 days the average number was 52.2 or complete mortality (Table 9). For T. castaneum under these conditions there was an average of 50 or complete mortality at the end of 60 days (Table 19).

In wheat with a moisture content of 12.2 percent, infested with 50 adult T. confusum, the average number of dead adults at the end of 60 days was 8.2, at the end of 120 days 33, and at the end of 180 days 42 (Tables 5, 11 and 15). For T. castaneum in 12.2 percent wheat the average number of dead adults at the end of 60 days was 43, at the end of 120 days 47, and at the end of 180 days 50.8 (Tables 21, 25 and 29).

In 20-gram samples of wheat with a moisture content of 14.2 percent, infested with 50 adult T. confusum, the average number of dead adults at the end of 60 days was 1.4, at the end of 120 days 2.2, and at the end of 180 days 2.8 (Tables 7, 13 and 17). In 14.2 percent, infested with T. castaneum, the average number of dead adults at the end of 60 days was 8.6, by the end of 120 days 12, and at the end of 180 days 25.6 (Tables 23, 27 and 31).

From the above discussion the moisture content appears to be an important factor in the mortality of these insects. As the moisture content of the wheat increases the mortality decreases. There was a much greater mortality rate for T. castaneum than for T. confusum.

The Effects of the Length of Infestation

Table 32 gives the average percentages of weight loss to the 20-gram samples of wheat and the average number of live insects present at the three different moisture levels at the end of each 60 day infestation period. The average total number of live insects was determined by adding the average number of increase to the original 50 adults minus the number of dead adults. For *T. confusum* at the end of 60 days the average percent of damage or weight loss to the 20-gram samples of wheat with a moisture content of 10.2 percent was 1.2 percent with a total of 20 insects remaining alive. At the end of 120 days the average percent of damage was 1.7 with no live insects, the insects having died

Table 32. The effects of the length of infestation of *T. confusum* and *T. castaneum* in 20-gram samples of whole kernel wheat of three moisture levels on the extent of damage to the wheat and on the extent of development of the insect populations.

	10.2% moist. cont.		12.2% moist. cont.		14.2% moist. cont.	
Days	Percent damage	Total insects	Percent damage	Total insects	Percent damage	Total insects
			confusum			
60	1.2	20	2.1	72	3.3	92
120	1.7	0	6.2	84	8.3	134
180	-	-	8.7	102	10.8	134
			castaneum			
60	0.9	0	1.3	15	2.4	55
120	-	-	1.7	18	3.0	56
180	-	-	2.1	24	3.7	53

during the second 60 day period. For T. castaneum the average percent of damage to the 20-gram samples of 10.2 percent wheat was 0.9 and no insects, the insects having died during the first 60 day period.

Tribolium confusum caused more damage to the 14.2 percent wheat during the second infestation period (60 to 120 days) than during the third infestation period (120 to 180 days). They caused 5 percent damage to the 20-gram samples of wheat during the second period as against 2.5 percent during the third period. The average total number of insects at the end of 120 days was 134 and at the end of 180 days 134. The explanation of this is suggested as follows: The insects reach an equilibrium with the amount of space or food medium in which they live and then destroy many of their immature stages, particularly eggs and pupae (Holdaway, 1932). This prevents a condition of overcrowding and the population tends to level off as shown graphically in Fig. 48. It is believed that the insects fed on their young in place of the wheat, causing less damage to the grain at the higher population level. The same is somewhat similar in the case of the 12.2 percent wheat. However, the insects did not reach their point of equilibrium during the last infestation period (Fig. 48).

Tribolium castaneum caused approximately the same amount of damage to the 14.2 percent wheat during the second period of infestation (60 to 120 days) as during the third period (120 to 180 days). They kept approximately the same number of live insects all through the 180 day period. This is believed to have been due mostly to the increasing rate of adult mortality. These insects caused the same amount of damage to the 12.2 percent wheat during the second infestation period (60 to 120 days) as during the third period (120 to 180 days). They did, however, have a slightly larger population at the end of 180 days than at the end of 120 days. *Tribolium castaneum* did not reach a population equilibrium or leveling stage during the entire 180 days as can be seen in Fig. 49. In both damage to the grain and extent of reproduction, *T. confusum* was 2 to 4 times more successful than *T. castaneum*.

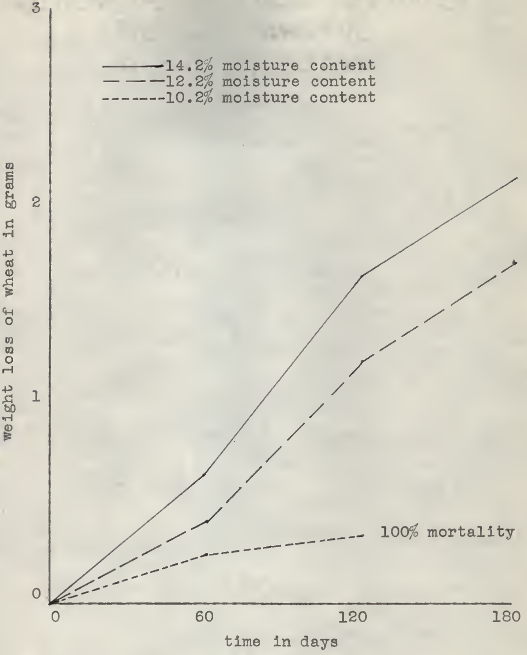


Fig. 46. Extent of damage by T. confusum to 20-gram samples of wheat of varying moisture contents over a 180 day period.

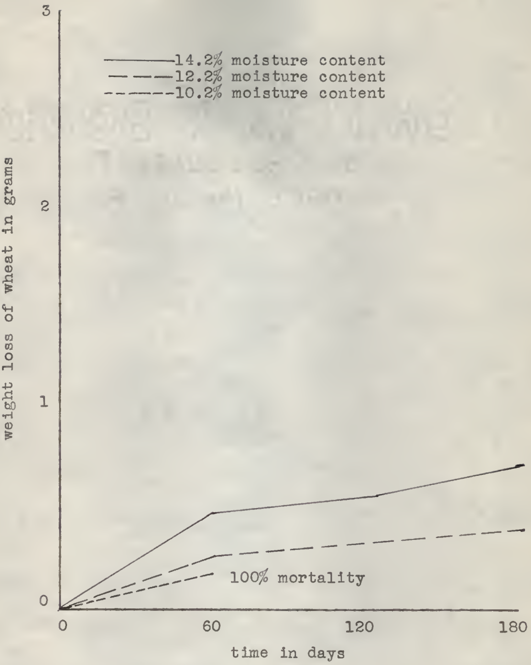


Fig. 47. Extent of damage by T. castaneum to 20-gram samples of wheat of varying moisture content over a 180 day period.

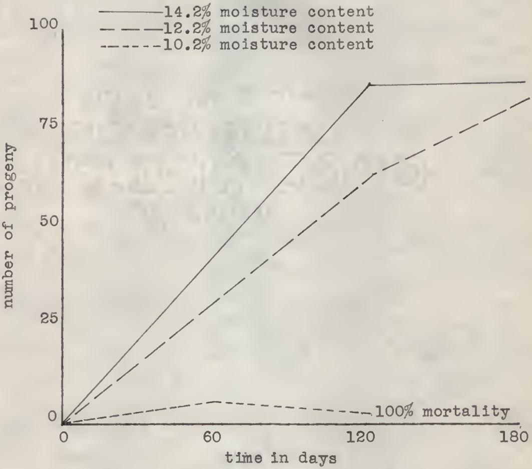


Fig. 48. Extent of reproduction of T. confusum in 20-gram samples of wheat of varying moisture contents over a 180 day period.

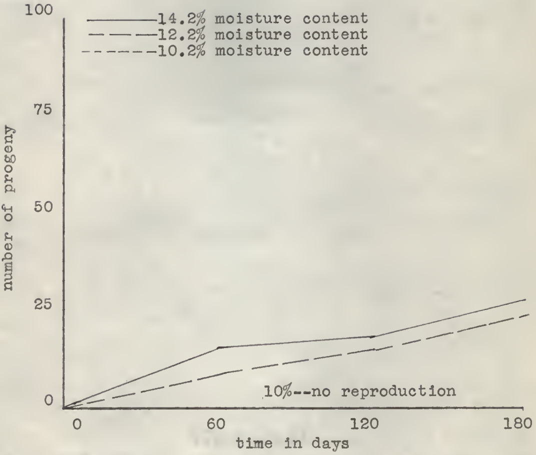


Fig. 49. Extent of reproduction of T. castaneum in 20-gram samples of wheat of varying moisture contents over a 180 day period.

CONCLUSIONS

The results of this experiment seem to warrant the following conclusions:

1. That when each of the two species of Tribolium, confusum and castaneum, are confined to whole kernel uncracked wheat over a period of 180 days, they are able to live, reproduce and cause an appreciable amount of damage to the grain which confirms Birch's original observations (1947).

2. That when the wheat is of three moisture levels, approximately 10 percent, 12 percent and 14 percent, the insects are more successful in producing progeny and also cause more damage in wheat with the highest moisture content than in wheat with the lowest moisture content.

3. That adult T. confusum are from 2 to 4 times more successful in producing progeny in whole kernel wheat than T. castaneum.

4. That T. confusum cause from 2 to 4 times more extensive damage to whole kernel wheat than T. castaneum.

5. That the moisture content of the wheat has a decided effect upon the survival of the insects. The time of survival is much longer in wheat with a high moisture content than in wheat with a low moisture content.

SUMMARY

The work in this investigation was conducted to obtain information regarding the damage to whole kernel wheat by T. con-

fusum and T. castaneum and also to determine the extent of their reproduction on whole kernel wheat. A six months' study was made of these insects infesting whole kernel wheat of three moisture levels approximately 10 percent, 12 percent and 14 percent at a constant temperature of 80° F.

Stock cultures of T. confusum and T. castaneum were reared on a mixture of 40 percent white patent flour and 60 percent wheat middlings or shorts. The sulfuric acid method was used in maintaining the humidity at the desired level, thus keeping the moisture content of the grain stable. This method consists in keeping the cultures in an atmosphere of constant humidity which is maintained by an aqueous solution of sulfuric acid of known specific gravity. Twenty-gram samples of whole kernel wheat of the three different moisture contents were infested with 50 adult insects. Five replications of each infested sample were left for periods of 60 days, 120 days and 180 days. Examinations of these respective samples were made at the end of each period and the weight loss or damage to the grain determined, the number of progeny recorded and the adults both live and dead counted.

It was found that the insects caused the most damage to the wheat with the highest moisture content. There was also a greater extent of reproduction in the wheat with the highest moisture level. Tribolium confusum caused more extensive damage to the wheat and was also more successful in reproduction than T. castaneum.

The average weight loss or extent of damage by T. confusum, confined to 20-gram samples of wheat with a moisture content of 10.2 percent, at the end of 60 days was 1.2 percent and the average total number of live insects was 20. At the end of 120 days this figure was 1.7 percent weight loss and no live insects. The insects died during the second infestation period (60 to 120 days). The average weight loss to the 20-gram samples of wheat, infested with T. castaneum, at the end of 60 days was 0.9 percent with no live insects present as they had died during the first 60 days.

In the wheat with a moisture content of 12.2 percent the average weight loss for T. confusum was 2.1 percent at the end of 60 days with an average total number of 72 live insects. At the end of 120 days 6.2 percent weight lose occurred with an average of 84 live insects per 20-gram wheat sample. By the end of 180 days there was an average of 8.7 percent damage to the wheat with an average population of 102 insects. For T. castaneum in wheat of the same moisture level the weight loss to 20-gram samples of wheat at the end of 60 days was 1.3 percent and the average size of the population in these samples was 15 insects. By the end of 120 days the average weight loss was 1.7 percent with an average population of 18 and at the end of 180 days 2.1 percent weight loss and 24 insects.

In the 14.2 percent wheat, infested with T. confusum, the average extent of damage by the end of 60 days was 3.3 percent and the average total number of live insects 92. By the end of 120 days these figures were 8.3 percent damage and 134 insects.

At the end of 180 days the average weight loss was 10.8 percent and the average population still 134. It is believed that at the end of 120 days T. confusum had reached a population equilibrium with their amount of food medium or living space and had destroyed their young to prevent overcrowding, thus causing less damage to the grain by living on their young and keeping the population stable. Damage caused by T. castaneum to 20-gram samples of wheat with a 14.2 percent moisture content averaged 2.4 percent at the end of 60 days with an average insect population of 55. The damage at the end of 120 days was 3 percent and the average total number of insects 56. By the end of 180 days in 14.2 percent wheat these figures were 3.7 percent damage with an average population of 53. Tribolium castaneum kept approximately the same size population during the 180 day period which is believed to have been due to the rate of adult mortality.

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THE EXTENT OF DAMAGE AND REPRODUCTION OF TRIBOLIUM CONFUSUM AND T. CASTANEUM IN WHEAT WITH DIFFERENT MOISTURE CONTENTS

by

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INTRODUCTION

The confused flour beetle, *Tribolium confusum* Duval, and the red flour beetle, *T. castaneum* Herbst, are well known insect pests of wheat flour and other food products in storage. Until recently it had been assumed that the flour beetles lived either on cracked kernels or on the "grain dust" caused by the abrasion of grains in handling or on the "flour-like" material resulting from the feeding of other insects. According to Cotton (1943) the adult flour beetles are able to survive for long periods of time in wheat but little damage will be done since they are unable to multiply and do not feed on whole grain. Good (1936) also advanced the idea that the genus *Tribolium* cannot feed upon whole grain because their mandibles are not strong enough to chew through the tough outer coating. Parkin (1944) stated that in different tests "broken grain" was employed because *T. confusum* is unable to feed on whole grain.

Upon observing the behavior of these insects Birch (1947) became skeptical and conducted an experiment to test this point. He found that both species could live and reproduce in whole grain wheat. After six months, about one-third of the grains had been damaged.

PURPOSE

The experimental work designed for this thesis had a twofold purpose: First, to obtain information regarding the extent of damage to the wheat kernels by Tribolium confusum and T. castaneum; and second, to determine the ability of these insects to reproduce on whole kernel uncracked wheat. For this reason a six months' study was made of these insects infesting wheat of three different moisture contents; 10 percent, 12 percent, and 14 percent, respectively, at a constant temperature of 80° F.

MATERIALS AND METHODS

Cultures

Stock cultures of these insects were reared in wide-mouthed pint jars on food medium of 40 percent white patent flour and 60 percent wheat middlings or shorts. Insects between the ages of 6 and 15 days were used in this experiment.

Establishing Moisture Levels of the Grain

The moisture content of the wheat was obtained and held constant by keeping the cultures in an atmosphere which is maintained at a constant humidity by exposure to an aqueous solution of sulfuric acid of known specific gravity. Stevens (1916) used this method in rearing fungi on fruits at a certain humidity. Battery jars 8" x 15" were convenient to use as the closed containers of humidifiers. The specific moisture content at which a certain relative humidity would hold small samples of wheat was found in the following manner: Two battery jars were set up at approximately 50 percent and 75 percent relative humidity. Samples of

155 grams of wheat in pint jars were placed in each humidifier. The moisture content of this grain, when placed in the large containers, was 11.7 percent. The moisture readings of these samples was taken every two days, by the use of the Steinlite Electric Moisture Tester. In about 10 days the readings begin to level off; that is, they begin to remain the same or very nearly so. The grain in the humidifier of 50 percent leveled off at about 9 percent moisture content and the grain in the humidifier of 75 percent at 12.2 (± 0.1 percent) moisture content. Water was then added in small amounts to the solution in the 50 percent jar until the grain reached a moisture content of 10.2 (± 0.1 percent). In using this trial and error method the following data were gathered:

Relative humidity %	Moisture content of grain %	Specific gravity of acid solution
60% ± 2	10.2 ± 0.1	1.29
75% ± 2	12.2 ± 0.1	1.23
90% ± 2	14.2 ± 0.1	1.14

Only a small amount of acid solution was required to maintain a constant humidity within a battery jar. The humidifiers were kept in a well insulated constant temperature room under conditions of 80° F. (± 1° F.) and a relative humidity of 50 percent to 60 percent.

Twenty-gram lots of wheat were each infested with 50 adult insects. The wheat was first thoroughly cleaned with a sieve and then cracked kernels were carefully eliminated. The wheat was then weighed out into 20-gram lots and each lot placed in one humidifier along with one 155-gram sample of wheat which was used for a moisture check. These 17 samples were weighed every five days and the moisture content taken every two days. The wheat gained or lost in moisture content according to the humidity within the humidifier. When the samples were reweighed, at the end of each five day interval, wheat was added to or removed from each sample to maintain the 20-gram sample. Within ten days the wheat would begin to level off in moisture content and at the end of approximately three weeks the moisture content was stabilized.

At the end of three weeks, or after the grain had reached a moisture content in equilibrium with the humidity, the 17 samples were reweighed and 15 of them were infested with 50 adult beetles. The two samples not infested were maintained as weight check or control jars.

Handling the Samples

The insects were collected with an aspirator, double checked for accurate count and then placed in a 20-gram wheat sample. After 15 of the samples had been infested, they were placed in the humidifier along with the two weight-control samples and the moisture check sample. The infestation periods of the wheat samples were two months, four months, and six months. Five of the samples were removed from the humidifier and examined at the end of 60 days, five more at the end of 120 days and the remaining five at the end of 180 days. The two weight-control samples were weighed and the moisture content of the 155-gram sample was taken at weekly intervals during the six months' period.

Calculations of Damage

The weight loss as stated in this thesis is figured on the basis of the loss or damage to the 20-gram wheat samples with the waste and feces removed. The difference in weight between the weight loss of the grain and the weight of the dust might be considered in part metabolic loss. However, the metabolic loss was not considered in this experiment, only the gross weight loss to the wheat. At the end of each infestation period, when five of the infested samples were examined, the insects were separated from the wheat. The wheat was then weighed and this weight subtracted from the weight of the control samples which were weighed as soon as they were removed from the humidifying chamber. By using this method, gain or loss in the weight of the wheat was known and the weight loss could be more accurately determined.

The insects were separated from the waste or dust by means of a 100-mesh screen sieve. In this way the young larvae were easily removed from the dust (waste and feces). The insects were then counted and the number of the various stages determined. After counting the larvae, a rough estimate was made of their different instars.

RESULTS

The only successful attacks on the whole wheat kernel were made at the end of the kernel containing the embryo. No grains were found in which the damage had started from the other end. After the grain embryo was removed, feeding frequently proceeded further into the kernel. About one-third of the kernels were damaged at each of the three moisture levels. However, the wheat with the highest moisture content had more grain shells or was damaged the most. A few of the grains were almost destroyed--only a mere shell was left.

Extent of Reproduction

The moisture content of the wheat appeared to be an important factor not only in the weight loss or damage of the grain but also in the extent of reproduction of these insects. In the 10.2 percent wheat there was little reproduction in *T. confusum* and none in *T. castaneum*. Larvae of *T. confusum* were found after the first 60 days but no pupae. However, at the end of 120 days, an average of 2.2 insects had reached the adult stage and died. In the wheat with a moisture content of 12.2 percent there was an increase of larval population in comparison with the 14.2 percent wheat and a small number of pupae. Upon examining and estimating the different larval instars there seemed to be a preponderance of last instar larvae. There were more of these large larvae of the same size than any of the other smaller instars. Chapman

(1918) stated that the life cycle of these beetles reared on different foods, under uniform conditions, may vary in length and that this difference in development is confined largely to the last larval instar. However, in this experiment there was an increase in number of the last larval instar when reared on the same food under different moisture conditions. There was a more equal distribution of the different instars of the larvae in the wheat with a 14.2 percent moisture content. Also in the 14.2 percent wheat there were more pupae and less larvae than in the 12.2 percent wheat. This indicates that the beetles developed and emerged faster in the 14.2 percent wheat than in the 12.2 percent wheat.

Mortality

The extent of mortality of the immature stages under the conditions in this experiment is not known because the insects may consume some of their eggs, larvae and pupae. The mortality of the adults was determined by counting the dead. These dead insects appeared to be mostly of the original 50 and not of their progeny. In 20-gram wheat samples with three moisture contents the adult mortality is as follows:

moisture content of wheat %	confusum	castaneum
10.2	100% mortality end of 120 days	100% mortality end of 60 days
12.2	42% mortality end of 180 days	85% mortality end of 180 days
14.2	2% mortality end of 180 days	40% mortality end of 180 days

Damage and Populations

Table 1 gives the average percentages of weight loss to the 20-gram samples of wheat and the average number of live insects present at three different moisture levels at the end of each 60 day infestation period. The average total number of live insects was determined by adding the average number of increase to the original 50 adults minus the average number of dead adults.

The average weight loss or extent of damage by T. confusum, confined to 20-gram samples of wheat with a moisture content of 10.2 percent, at the end of 60 days was 1.2 percent and the average total number of live insects 20. At the end of 120 days this figure was 1.7 weight loss and no live insects. The insects had died during the second infestation period (between 60 and 120 days). The average weight loss to the 20-gram samples of wheat, infested with T. castaneum, at the end of 60 days was 0.9 percent with no live insects present as they had died during the first 60 days.

Table 1. The extent of damage or weight loss and the extent of development of the insect populations in wheat of different moisture contents for T. confusum and T. castaneum at the end of each infestation period.

Days	10.2% moist. cont.		12.2% moist. cont.		14.2% moist. cont.	
	Percent damage	Total insects	Percent damage	Total insects	Percent damage	Total insects
			confusum			
60	1.2	20	2.1	72	3.3	92
120	1.7	0	6.2	84	8.3	134
180	-	-	8.7	102	10.8	134
			castaneum			
60	0.9	0	1.3	15	2.4	55
120	-	-	1.7	18	3.0	56
180	-	-	2.1	24	3.7	53

In the wheat with a moisture content of 12.2 percent the average weight loss for T. confusum was 2.1 percent at the end of 60 days with an average total number of 72 live insects. At the end of 120 days 6.2 percent weight loss occurred with an average of 84 live insects per 20-gram wheat sample. By the end of 180 days there was an average of 8.7 percent damage to the wheat with an average population of 102 insects. For T. castaneum in wheat of the same moisture level the weight loss to 20-gram samples of wheat at the end of 60 days was 1.3 percent and the average size of the population in these samples was 15 insects. By the end of 120 days the average weight loss was 1.7 percent with an average population of 18 and at the end of 180 days 2.1 percent weight loss and 24 insects.

In the 14.2 percent wheat, infested with _T. confusum_, the average extent of damage by the end of 60 days was 3.3 percent and the average total number of live insects 92. By the end of 120 days these figures were 8.3 percent damage and 134 insects. At the end of 180 days the average weight loss was 10.8 percent and the average population still 134. It is believed that at the end of 120 days _T. confusum_ had reached a population equilibrium with their amount of food medium or living space and had destroyed their young to prevent over-crowding, thus causing less damage to the grain by living on their young and keeping the population stable. Damage caused by _T. castaneum_ to 20-gram samples of wheat with a moisture content of 14.2 percent averaged 2.4 percent at the end of 60 days with an average insect population of 55. The damage at the end of 120 days was 3 percent and the average total number of insects 56. By the end of 180 days in 14.2 percent wheat these figures were 3.7 percent damage with an average population of 53. _Tribolium castaneum_ kept approximately the same size populations during the 180 day period which is believed to have been due to the rate of adult mortality.